BOSTON PUBLIC LIBRARY
3 9999 06317 769 3

198, 199

ANALYSIS AND MACHINE MAPPING OF THE DISTRIBUTION OF BAND RECOVERIES

Special Scientific Report—Wildlife No. 198

COMPUTERIZED TABULATION AND DISPLAY OF BAND RECOVERY DATA

Special Scientific Report—Wildlife No. 199

United States Department of the Interior

Fish and Wildlife Service

ANALYSIS AND MACHINE MAPPING OF THE DISTRIBUTION OF BAND RECOVERIES

Special Scientific Report—Wildlife No. 198

by Lewis M. Cowardin

COMPUTERIZED TABULATION AND DISPLAY OF BAND RECOVERY DATA

Special Scientific Report—Wildlife No. 199

by D. Alan Davenport

United States Department of the Interior

Fish and Wildlife Service

Washington, D.C. • 1977

ANALYSIS AND MACHINE MAPPING OF THE DISTRIBUTION OF BAND RECOVERIES

by

Lewis M. Cowardin

U.S. Fish and Wildlife Service
Northern Prairie Wildife Research Center
P.O. Box 1747, Jamestown, North Dakota 58401

Abstract

A method of calculating distance and bearing from banding site to recovery location based on the solution of a spherical triangle is presented. *X* and *Y* distances on an ordinate grid were applied to computer plotting of recoveries on a map. The advantages and disadvantages of tables of recoveries by State or degree block, axial lines, and distance of recovery from banding site for presentation and comparison of the spatial distribution of band recoveries are discussed. A special web-shaped partition formed by concentric circles about the point of banding and great circles at 30-degree intervals through the point of banding has certain advantages over other methods. Comparison of distributions by means of a X^2 contingency test is illustrated. The statistic $V = X^2/N$ can be used as a measure of difference between two distributions of band recoveries and its possible use is illustrated as a measure of the degree of migrational homing.

Recoveries of banded birds can be used to estimate many important parameters necessary for an understanding of the dynamics of a population. Anderson (1972) and Seber (1973) reviewed methods of analysis for determining population size and survival and prepared an extensive bibliography. Geis (1972) described the role of banding data in management and outlined some methods for analysis. One of the oldest, and still one of the most important uses of banding data is for the examination of the spatial distribution of recoveries to determine areas of breeding, wintering, migration, and harvest, as well as degree of homing. Many methods have been used for depicting and comparing the distribution of band recoveries. The simplest of these is a tabulation by State and Province (e.g., Geis and Cooch 1972). Miller et al. (1968) presented data on a map by using circles with areas proportional to numbers of recoveries by State and Province. Numbers of recoveries also may be tabulated by degrees of latitude and longitude, and the table may then be adapted to a map (e.g., Anderson and Henny 1972:23). The numbers may be grouped and converted to gray tones to convey the impression of density of harvest (e.g., Lensink 1964:131). If the quantity of recoveries is relatively small, each recovery may be depicted as a point on a map (e.g., Moyle 1964:113). Bellrose and Crompton (1970) made effective use of axial lines, which are constructed by connecting points of mean longitude for all recoveries at various degrees of latitude. The authors used this method of displaying the distribution of band recoveries to illustrate migrational corridors.

The purposes of this paper are to: (1) describe methods that facilitate plotting band recoveries on maps, (2) evaluate numerical treatments of spatial distributions of band recoveries, (3) suggest a new method for expressing and comparing distributions, and (4) examine some of the biological implications of differences in recovery distributions. Methods that are adaptable to machine processing are stressed because of the ease with which records supplied by the U.S. Fish and Wildlife Service (FWS) or the Canadian Wildlife Service may be read by machine (Cowardin and Davenport 1973, Salvadori and Youngstrom 1973). I have not attempted to review the many biases and possibilities for misinterpretation of banding data (see Crissey 1955; Gollop 1963; Anderson and Henny 1972; Geis 1972). Computer programs suitable for execution of many of the procedures presented here are described by Davenport (1977).

I acknowledge the assistance of D. A. Davenport in development of methods. D. H. Johnson furnished valuable advice and reviewed the manuscript.

Distance and Bearing from Banding to Recovery

The distance and bearing from banding site to recovery site are useful measurements descriptive of migratory movement. They also furnish the means for machine plotting of recoveries on a map and are used in constructing other measures of distribution described later.

Records furnished by the Bird Banding Laboratory of the U.S. Fish and Wildlife Service contain the latitude and longitude of the southeast corner of a rectangular unit (10 minutes on a side) containing the banding or recovery site. Given these data, it is possible to calculate the distance and bearing from banding to recovery location by solving a spherical triangle *NBR* where *N* is the North Pole, *B* is the banding site, and *R* is the recovery site. These points are known and are expressed in degrees in the earth's spherical coordinate system. The bearing from *B* to *R* is calculated relative to *N* (bearing of 0) and lies between 0° and 360° (Robinson and Sale 1969; Bowditch 1962). To avoid ambiguity as to which quadrant contains the solution, Haversine formulas were used to calculate the bearing. Distances were calculated in degrees and converted to units of radius of the earth, a common cartographic procedure. Calculation of distance and angle from point *B* to point *R* is as follows:

Let B_{lat} = Latitude of banding location,

B_{long} = Longitude of banding location,

R_{lat} = Latitude of recovery location,

R_{long} = Longitude of recovery location, and

$P = B_{\text{long}} - R_{\text{long}}$.

Then *D*, the distance between *B* and *R* in degrees, is determined:

$$D = \text{Cos}^{-1}\left\{(\text{Sin } B_{\text{lat}} \times \text{Sin } R_{\text{lat}}) + (\text{Cos } B_{\text{lat}} \times \text{Cos } R_{\text{lat}} \times \text{Cos } P)\right\},$$

and *C*, the original great circle bearing from *B* to *R*, is determined as follows:

$$C = \text{Hav}^{-1}\left\{(\text{Sec } B_{\text{lat}} \times \text{Csc } D \times [\text{Hav}\,(90°-R_{\text{lat}}) - \text{Hav}|D - (90° - B_{\text{lat}})|]\right\},$$

where $\text{Hav } A = \tfrac{1}{2}(1 - \text{Cos } A)$ and

$$\text{Hav}^{-1} A = \text{Cos}^{-1}(1 - 2\,\text{Hav } A).$$

The latitude and longitude data in FWS statistical recovery records are in degrees and minutes and must be changed to decimal degrees before the above formulas can be used. For example, 472 in the latitude field of a FWS Statistical Recovery Record means 47° 20′, and 20′/60′ = 0.33°; therefore, the latitude = 47.33°. The above formula for *C* yields a bearing between 0° and 180°. If the recovery is west of the banding (indicated by *P* negative), it is necessary to add 180° to the bearing *C*.

Automatic Plotting of Recoveries on Maps

If the number of recoveries to be plotted is small, it is a simple matter to plot them by hand on a map with a suitable graticule (i.e., network of latitude and longitude lines). But as the number of recoveries increases, plotting them becomes exceedingly tedious and time-consuming. The investigator may desire plots for a number of combinations of species, age, and sex, which again increases the labor of hand plotting. Machine plotting furnishes a rapid yet meaningful means of examining the recovery pattern and saves time in drafting final maps for reports or publication.

Automatic plotting requires that the latitude and longitude be converted from the graticule of the map projection to the *X* and *Y* coordinates of the plotter bed. Davenport (1976) developed a program that plots recovery data on a square grid representing latitude and longitude. This square grid is quite useful for preliminary examination of the data or as an aid to hand plotting, but is not suitable for a map projection primarily because of distortion in area. A discussion of the uses of various map projections is beyond the scope of this paper; the interested reader is referred to Robinson and Sale (1969).

One of the most common map projections for North America is the Lambert Azimuthal Equal Area Projection centered at 40°N latitude, 100°W longitude. This is an excellent projection for machine plotting of North American band recoveries for three reasons: (1) good quality base maps are readily available, (2) the projection is equal area so that density of recoveries is not distorted on the map, and (3) the formula of projection is simple, which facilitates conversion to *X* and *Y* coordinates for plotting. Because the projection is azimuthal, great circles through the point of tangency (40°N, 100°W) appear as straight lines on the map. If we consider the point of tangency as the origin of an (*X*,*Y*)-coordinate system, the formulas presented earlier can be modified by letting the banding location equal the point of tangency, which is a constant. The distance and bearing from the point of tangency to the recovery are then:

$$D = \text{Cos}^{-1}\left\{(0.64279 \times \text{Sin } R_{\text{lat}}) + [0.76604 \times \text{Cos}\,(R_{\text{lat}}) \times \text{Cos}\,(100°-R_{\text{long}})]\right.$$

and

$$C = \text{Hav}^{-1} \{1.30541 \times (\text{Csc } D) \times [\text{Hav}(90° - R_{\text{lat}}) - \text{Hav} \mid D - 50° \mid]\}$$

For mapping, D may be converted from degrees to units of the earth's radius:

$$Dr = \frac{\pi}{180°} D.$$

To plot the recovery, the X and Y distances from the origin are calculated by plane trigonometry:

$$X = Dr \times \text{Sin } C \text{ and } Y = Dr \times \text{Cos } C.$$

Davenport (1977) developed a simple Fortran program to determine these values. Once the user has the basic software for point plotting, it is relatively simple to modify it for shading proportional to the number of recoveries per unit area on the map.

Comparing Distributions of Band Recoveries

Methods that have been used for examination, summary, and analysis of the pattern of band recoveries are either pictorial or tabular. Attempts made to combine the two have not been altogether successful.

Maps. Maps are particularly valuable as a first step in examining a set of banding data. Representing recoveries by points or shading often gives the biologist an intuitive feeling for the importance of various areas, for example, refuges, areas of prime habitat, or regions of heavy hunting pressure. There are, however, several problems associated with map presentations: (1) In areas where there are many recoveries, map symbols become superimposed and illegible; conversely, isolated recoveries become inconspicuous unless the symbol is large relative to the map scale. (2) It is difficult to present numerical data on a map. Gray tones or circles proportional to the number of recoveries aid the pictorial representation at the expense of the quantitative data. Printing numbers by degree-block is fairly successful, but the numbers must be small relative to the map scale, particularly in northern latitudes where degree blocks are long and narrow. (3) Without the aid of a statistical test, it is difficult to determine whether the observed differences in distributions reflect real differences or merely chance variation.

Axial line plots. Bellrose and Crompton (1970) described the method of axial lines for expressing the distribution of recoveries on a map. The method is useful, but large samples are required for the technique to be effective. They stated that the lines drawn at one standard deviation on either side of the axial line contain about two-thirds of the recoveries. This is true if the longitudes of recovery are normally distributed. In fact, the distribution is more likely to be skewed or bimodal or include aberrant data. The median longitude and selected quartiles may be more suitable for expressing migrational corridors because these statistics are less affected by non-normality. There is also a tendency to view incorrectly the lines connecting points at one standard deviation on either side of the mean as the borders of the corridor. Furthermore, the standard deviation lines do not necessarily include two-thirds of all recoveries because they are placed around the sample mean, which may vary considerably from the true mean. It is, however, useful to have a measure of variability to compare axial lines.

Tables by political unit. Tabulation of numbers of recoveries by State and Province is a useful technique, particularly for examining harvest statistics, which are affected by varying harvest regulations among States. The tabulation is simple because the States in which banding and recovery occur are coded on the FWS statistical recovery record. The difference between two distributions, for example direct and indirect, can be compared by means of a χ^2 contingency test in a $2 \times k$ table where k equals the number of States. There are several disadvantages of tabulation by State: (1) much detail is lost, (2) State boundaries do not necessarily coincide with those of the ecological units that determine the distribution of birds, and (3) States vary in size. Generally the majority of band recoveries come from a few States; the remainder are scattered widely among many States. This type of distribution requires grouping data from several States in order to use the χ^2 test. The results will vary depending on how the States are grouped.

Tables by degree block. The lack of resolution associated with tabulation of recoveries by State can be overcome by tabulating recoveries by degree blocks. This technique is most effective when a large sample of recoveries is available. When sample sizes are small, there are so many cells with few observations that the use of χ^2 for comparing distributions becomes questionable. Although far more uniform in size than States, degree blocks also vary in size, particularly if the recovery data extend over a wide range of latitudes.

Proximity of recovery to banding. If the proximity of recovery to the banding site is of interest, it is possible to calculate the percentage of recoveries falling within a predetermined number of degree blocks from the banding site. This technique is particularly useful for examining the importance of

local hunting mortality, but it suffers to some extent because much of the detail available in the data is lost and no use is made of the direction of recoveries from the banding site. Two different distributions may be compared by X^2 in a 2 × 2 contingency table.

New System for Partitioning Band Recovery Data

A new system for tabulating banding data was devised in an attempt to overcome some of the problems presented by other methods. The system was designed to quantify and standardize data and to facilitate comparison between two distributions of recoveries. It is based on a web-shaped partition formed by concentric circles around and great circles through the banding site (Fig. 1). The central cell of the partition is a circle of radius 20 km centered on the banding site. The concentric circles have geometrically increasing radii of 20, 40, . . . , and 5120 km. The great circles begin with the north-south line and are spaced at 30° intervals. The recoveries are tabulated (Table 1) by determining the number falling in each cell of the partition. The partition is designed to view the distribution of recoveries in most detail near the banding site where data are most numerous and to combine data in distant areas where fewer recoveries are available. The recovery for each bird is examined in relation to the banding site for that bird. The cells of the partition cannot be related to a specific geographic area unless all bandings are from the same site. For example, if banding data for an entire State were used in the analysis, all recoveries of birds that were taken in the same 10

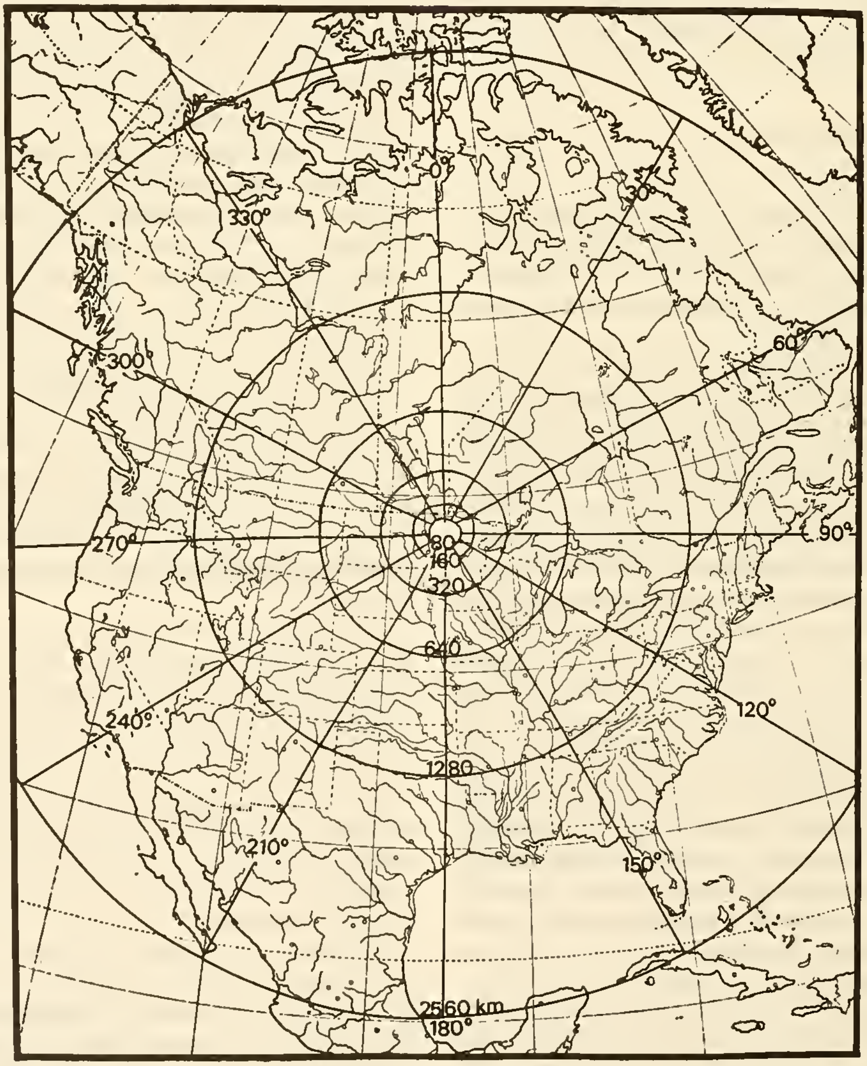

Fig. 1—Web-shaped portion for band recoveries centered on the banding site at the Chippewa National Forest, Minnesota (472N,0943W). Concentric circles at 20 and 40 km are now shown.

Table 1. *Distribution of 342 direct band recoveries for local male mallards banded at the Chippewa National Forest, Minnesota, 1953-1971.*

Distance (km)	Bearing (degrees)											
	0-30	31-60	61-90	91-120	121-150	151-180	181-210	211-240	241-270	271-300	301-330	331-360
0-20 (Banding site) 67[a]	—	—	—	—	—	—	—	—	—	—	—	—
21-40	2	4	4		6	3	2	12		1	4	
41-80			2	6	5	3		5	5	5	1	1
81-160	1		1		4	5	3	11	2	4	3	
161-320					4	17	21	10	4			1
321-640					11	20	8			4	2	2
641-1280				2	10	21	1				2	
1281-2560				2	2	23	1					

[a] No bearing can be determined within the banding site, which is defined as a circle.

minute block where they were banded would appear in the same cell of the partition even though the recoveries might be from different geographic areas. The tabulation summarizes distance and direction from banding to recovery relative to the banding site. In many applications, such as the examples illustrated later, all bandings are from the same area; therefore, the cells in the tabulation may be related to geographic areas (Fig. 1).

Determining which cell of the partition contains the recovery is complicated by the fact that compass bearings along a great circle change constantly except for north-south great circles and east-west bearings on the equator. To determine which great circles bracket a given recovery, I first calculated the distance from banding to recovery, as illustrated earlier. Then I calculated L, the latitude at that distance on each of 12 great circles.

$$L = 90^\circ - \mathrm{Hav}^{-1}\left\{\frac{\mathrm{Hav}\ C'}{\mathrm{Sec}\ B_{\mathrm{lat}}\ \mathrm{Csc}\ D} + \mathrm{Hav}\ \left| D\text{-}(90^\circ\text{-}B\mathrm{lat}) \right| \right\},$$

where

C' = Original great circle bearing, in our case 30°, 60°, 90°, . . . , 360°.

Davenport (1977) presented an algorithm for tabulating the results of this procedure. The tabulation (Table 1) is of value by itself as a rapid summary of data, and is well suited to a comparison of two distributions of band recoveries. The comparison of two tables is facilitated by the use of a $2 \times k$ contingency table where k equals the number of cells in the partition. The total X^2 for all cells in the $2 \times k$ table furnishes a test of significance of difference between the tables. Although the statistical significance of a calculated X^2 can be accurately assessed only if more than two-thirds of the expected cell frequencies are greater than five and none less than one (Lancaster 1969), a situation that is unlikely in the analysis of banding data, it is possible to judge informally the goodness of fit. Moreover, examination of the individual cell X^2 values aids in identification of those cells that show greatest departure from expectation. To measure similarity between two distributions, I used the coefficient of association, $V = X^2/N$, which takes values between 0 and 1 (Kendall and Stuart 1967:557). Low V values show similarity between two distributions. As a "rule of thumb" for 2×2 tables, Fleiss (1973:42) stated that coefficients of association less than 0.30 or 0.35 indicate similarity between the two distributions. An advantage of V is that it, unlike X^2, is independent of sample size.

Some Potential Uses of the Web-Shaped Partition

Data derived from the web-shaped partition of banding data may be used to test various hypotheses about distributions of band recoveries. For example, I wished to determine if there was evidence of difference between males and females in the distribution of direct band recoveries for 629 mallards (*Anas platyrhynchos*) banded locally at the Chippewa National Forest, Minnesota (Tables 1, 2). Although the patterns of distribution of harvest of males and females were generally similar (V = 0.108), large sample size and a difference in one cell yielded a large X^2 (67.86, d.f. = 55). More females than expected were shot at the banding site. R. E. Kirby (Ph.D. Thesis, University of Minnesota, in preparation) demonstrated that prior to the hunting season young

Table 2. *Distribution of 287 direct band recoveries for local female mallards banded at the Chippewa National Forest, Minnesota, 1953-1971.*

Distance (km)	Bearing (degrees) 0-30	31-60	61-90	91-120	121-150	151-180	181-210	211-240	241-270	271-300	301-330	331-360
0-20 (Banding site) 90[a]	—	—	—	—	—	—	—	—	—	—	—	—
21-40	1	2	1		7	4	1	13		6	2	
41-80			2	2	2	3	1	2			1	1
81-160		2	1	1		3	2	4		3		
161-320	1				3	8	12	6	4		3	1
321-640					8	13	2	2		5	2	1
641-1280				4	9	19	3					
1281-2560					3	18	3					

[a] No bearing can be determined with the banding site, which is defined as a circle.

Table 3. *Chi-square values for cells making a major contribution to total χ^2 for a 2 × k contingency table which compares 1963-1966 with 1967-1972 indirect band recoveries from geese banded at Sand Lake NWR.*[a]

Cell		1963-66			1967-72		
Distance (km)	Bearing (degrees)	Observed	Expected	χ^2	Observed	Expected	χ^2
Banding site		65	48.4	5.737	41	57.7	4.810
21-40	000-030	15	8.2	5.616	3	9.8	4.710
641-1280	181-210	11	35.1	16.56	66	41.9	13.89

[a] For complete table $N = 2107$, $\chi^2 = 152.159$, d. f. = 64, $V = 0.0722$

males leave the natal marsh earlier and move further than young females. This behavior could explain why disproportionately more females were recovered near the banding site.

In another test, I compared the recovery pattern of 1963-66 with that of 1967-72 for the distribution of indirect recoveries of Canada geese (*Branta canadensis*) banded at Sand Lake National Wildlife Refuge, South Dakota. The test yielded a χ^2 of 152.16 with 64 d.f. Examination of the individual cell values revealed that the major contribution to χ^2 resulted from shifts in distribution in three cells (Table 3). Fewer birds than expected were taken at the banding site and in the cell 21-40 km northeast (0°-30°) and more birds than expected were taken 641-1280 km southwest (181°-210°). The result from the first two cells agrees with general observations of a declining harvest near the refuge in recent years. The increase in the latter cell reflects a recent shift in harvest of Sand Lake banded birds to Kansas. The *V* value is low (0.072) and apparently in conflict with the large χ^2. This fact is informative because the sample size is very large, which enables very small differences between distributions to be detected. The *V* value shows that the distributions are generally quite similar. This situation is analogous to a small but significant correlation coefficient, which is obtainable with large samples.

Waterfowl tend to home to the area where they nested the previous year or to the area where they were raised (Lincoln 1934; Sowls 1955). Pair formation takes place on the wintering ground, and hens apparently determine the destination of the pair in spring migration. The drakes migrate north with a hen that may or may not have come from the same area as the drake (McKinney 1965). Homing is, therefore, not as strong in the male as the female. This trait suggests a hypothesis that the distribution of direct and indirect recoveries should be more similar for females than for males. The *V* statistic furnishes a measure of difference between distribution of direct and indirect recovery patterns. The difference in distribution reflects a difference between the sexes either in migrational homing or in differential fall migration. This hypothesis was tested on a data set composed of the recoveries of

Table 4. *Chi-square values for cells making a major contribution to total X^2 for a 2 × k contingency table which compares direct and indirect band recoveries for male mallards banded as locals at the Chippewa National Forest, Minnesota from 1953-1972.*[a]

Cell		Direct			Indirect		
Distance (km)	Bearing (degrees)	Observed	Expected	X^2	Observed	Expected	X^2
Banding site		67	48.2	7.362	3	21.8	16.243
1281-2560	151-180	23	48.9	13.684	48	22.1	30.194

[a] For complete table N = 497, X^2 = 213.354, d.f. = 57, V = 0.429.

mallards banded at the Chippewa National Forest and shot or found dead during hunting seasons from 1954 to 1972. Male mallards had a V value of 0.429 and females a value of 0.157. It is informative to examine the individual cell X^2 values to determine those cells with the greatest departure from expectation (Table 4). The banding site has far fewer indirect recoveries for males than would be expected under the hypothesis of no difference between distributions. This is because the majority of the males did not home to the banding site or, if they did, they left before the hunting season and were shot elsewhere. The cell for 1281–2560 km distant and 151°–180° had more indirect recoveries of males than expected. The disproportionately large number of indirect recoveries in the latter area, which contains the primary wintering ground for birds banded in the Chippewa National Forest, was probably because the same area is a primary harvest area for birds from the prairie pothole region as well as Minnesota (Anderson and Henny 1972; Gollop 1963). The direct and indirect recovery patterns for female mallards, which were very similar in all cells, supported the hypothesis of strong migrational homing in the female.

The method presented here is solely a mathematical means designed to quantify distributions and facilitate comparisons of patterns. Careful biological reasoning is essential for the selection of methods to be used in analysis of distribution of band recoveries and for interpretation of results. It is hoped that the development of machine methods will free the biologist from some of the time-consuming tasks of data inspection and make possible in-depth analysis and interpretation of banding data.

LITERATURE CITED

Anderson, D. R. 1972. Bibliography on methods of analyzing bird banding data. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Wildl. 156. 13 pp.

Anderson, D. R., and C. J. Henny. 1972. Population ecology of the mallard. 1. A review of previous studies and the distribution and migration from breeding areas. U.S. Fish Wildl. Serv. Resour. Publ. 105. 166 pp.

Bellrose, F. C., and R. D. Crompton. 1970. Migrational behavior of mallards and black ducks as determined from banding. Illinois Nat. Hist. Surv. Bull. 30(3):167–234.

Bowditch, N. 1962. American practical navigator. U.S. Navy Hydrographic Office, Washington, D.C. 1524 pp.

Cowardin, L. M., and D. A. Davenport. 1973. Computerized system for organizing and maintaining files of banding data. Bird-Banding 44(3):187–195.

Crissey, W. F. 1955. The use of banding data in determining waterfowl migration and distribution. J. Wildl. Manage. 19(1):75–84.

Davenport, D. A. 1977. Computerized tabulation and display of band recovery data. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Wildl. 199. 7 pp.

Fleiss, J. L. 1973. Statistical methods for rates and proportions. John Wiley & Sons, New York. 223 pp.

Geis, A. D. 1972. Use of banding data in migratory game bird research and management. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Wildl. 154. 47 pp.

Geis, A. D., and F. G. Cooch. 1972. Distribution of the duck harvest in Canada and the United States. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Wildl. 151. 11 pp.

Gollop, B. J. 1963. Autumnal distribution of young mallards banded at Kindersley, Saskatchewan. Proc. Int. Ornithol. Congr. 13:855–865.

Kendall, M. G., and A. Stuart. 1967. The advanced theory of statistics. Vol. 2. Hanfner Publishing Co., New York. 690 pp.

Lancaster, H. O. 1969. The Chi-squared distribution. John Wiley & Sons, New York. 356 pp.

Lensink, C. J. 1964. Distribution of recoveries from bandings of ducklings. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Wildl. 89. 146 pp.

Lincoln, F. C. 1934. The operation of homing instinct. Bird-Banding 5(4):149–155.

McKinney, F. 1965. Spacing and chasing in breeding ducks. Annu. Rep. Wildfowl Trust 16:92–106.

Miller, H. W., A. Dzubin, and J. T. Sweet. 1968. Distribution and mortality of Saskatchewan-banded white-fronted geese. Trans. N. Am. Wildl. Nat. Resour. Conf. 33:101–119.

Moyle, J. B., ed. 1964. Waterfowl in Minnesota. Minnesota Dept. Conserv. Tech. Bull. 7. 210 pp.

Robinson, A. H., and R. D. Sale. 1969. Elements of cartography. John Wiley & Sons, New York. 415 pp.

Salvadori, A., and K. A. Youngstrom. 1973. A system survey of a bird observatory: Part 1. A recording form for banding data. Bird-Banding 44(4):249–257.

Seber, G. A. F. 1973. The estimation of animal abundance and related parameters. Griffin, London. 506 pp.

Sowls, L. K. 1955. Prairie ducks. The Stackpole Co., Harrisburg, Pa., and The Wildlife Management Institute, Washington, D.C. 193 pp.

COMPUTERIZED TABULATION AND DISPLAY OF BAND RECOVERY DATA

by

D. Alan Davenport

U.S. Fish and Wildlife Service
Northern Prairie Wildlife Research Center
P.O. Box 1747, Jamestown, North Dakota 58401

Abstract

Recovery records from banded birds are ideally suited to computer processing. A data editing routine and five programs to tabulate band recovery data for analysis are presented with examples of each program's application. One of the programs produces a printer plot of North America simulating a Lambert Azimuthal Equal-area projection on which recovery or banding locations are plotted. Modification of the procedure to permit plotting of recoveries on maps is discussed and illustrated.

Recoveries of banded birds can provide a great deal of information about population dynamics and distribution of a species. The purpose of this paper is to describe several useful computer programs for tabulating and examining band recoveries. I acknowledge the assistance of L. M. Cowardin in development of some of the concepts. D. H. Johnson provided valuable advice and reviewed the manuscript.

The Bird Banding Laboratory of the U.S. Fish and Wildlife Service prepares a "Recovery Statistical Record" for each band recovered and reported. These records are in the form of punched cards or magnetic tape and are suitable for computer input. In Canada the records are available from the Banding Office of the Canadian Wildlife Service. Each record contains 14 fields of information about the banded bird, any or all of which could be pertinent for a given analysis. They are: (1) date of recovery, (2) how obtained, (3) who reported, (4) present condition, (5) why reported, (6) where recovered, (7) bander permit number, (8) species, (9) status of bird when banded, e.g., normal wild-caught, color-marked, (10) age, (11) sex, (12) where banded, (13) date banded, and (14) number of hunting seasons survived. Dates are by month, day, and year. Locations consist of codes for flyway, State, latitude and longitude by 10 minute blocks, and direction (north or south of the equator). Codes are described in the North American Bird Banding Manual, Vol. 1, 1976, prepared jointly by the U.S. Fish and Wildlife Service and the Canadian Wildlife Service.

The programs described here were written to extract, display, and/or summarize information from the recovery records.

EDITOR

EDITOR is a FORTRAN subroutine which selects specific data from a file of recovery records for further tabulation or summarization according to the requirements of the analysis. EDITOR is used by all FORTRAN programs reported in this paper to check location and date of banding and recovery, how obtained, permit number, AOU number, status, age, sex, and seasons survived against editing specifications coded on a control card.

Up to 5 flyway codes and 20 State codes may be specified for selection. Latitude and longitude may be selected as a single point or an inclusive range of values. Occasionally latitude and longitude are unknown or inexact and are coded accordingly; these values may be excluded if desired. Month, day, and year also may be coded as a single value or an inclusive range. Up to five additional codes may be used to specify inexact months, e.g., 93 = fall, 94 = hunting season. Sometimes day of recovery is unknown and estimated from postmarks or by 10-day period. Inexact day codes are automatically selected if the estimated date falls within the specified range. Up to 5 "how obtained" codes, 10 bander permit numbers, 10 AOU numbers, 10 status codes, 8 age codes, and 5 sex codes can be employed. Direct recoveries (banded and recovered in the same year) or

indirect recoveries (banded and recovered in different years) may be specified through the "seasons survived" parameter.

When all records have been processed, a summary of the editing is printed showing the numbers of records read, accepted, and rejected (due to invalid data, etc.). A list of parameters for which rejections were registered and numbers of rejections is also provided. Optional listings of complete record images also may be specified. EDITOR requires 16,180 bytes of storage plus system overhead.

RCOVTAB

RCOVTAB is a general tabulation program written in FORTRAN to show when, where, and how many recoveries occurred. "When" may be expressed as calendar year; season, e.g., hunting season, October-January; 10-day period in the months September-January; or the number of hunting seasons survived. "Where" may be categorized by State of banding or recovery, or by permit number of bander. The output may be segregated by species, status, age, and sex of banded birds.

Options are available to list total recoveries by year over a 10-year period by: (1) recovery State identifying States where banded, (2) banding State identifying States where recovered, (3) recovery State identifying bander permit numbers, (4) bander permit number identifying States where recovered. Each of the above also can be listed according to "seasons-survived" code rather than year. Additional listings by "seasons-survived" code are possible for banding State or bander permit number identifying year or season of banding. Recoveries occurring in 10-day periods from September through January may be listed by: (1) recovery State identifying States where banded, (2) banding State identifying States where recovered, (3) bander permit number identifying States where recovered.

Fig. 1 illustrates a tabulation by banding State, identifying States where recovered using 514 direct recoveries of local mallards (*Anas platyrhynchos*) banded on the Chippewa National Forest in Minnesota from 1955 to 1971. If banding had been from more than one State, separate tables would have been generated for each banding State. RCOVTAB requires 26,908 bytes of storage plus the EDITOR and system overhead.

BREAKDOWN OF BAND RECOVERIES BY RECOVERY LOCATION. CHIPPEWA BANDED LOCAL MALLARDS - DIRECT RECOVERIES PAGE 1

RECOVERY LOCATION	TOTAL	RECOVERY YEARS 1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	OTHER YEARS
MANITOBA	11	2	0	0	0	0	0	2	2	2	1	2
ONTARIO	2	0	0	0	0	0	0	0	0	1	1	0
SASKATCHEWAN	1	0	0	0	0	0	0	0	1	0	0	0
NORTH DAKOTA	14	1	0	1	0	2	1	1	2	2	1	3
MINNESOTA	348	10	27	25	4	16	14	20	16	63	41	112
WISCONSIN	28	2	4	3	1	0	2	0	1	6	0	9
MICHIGAN	2	0	0	0	0	0	1	0	1	0	0	0
SOUTH DAKOTA	5	0	0	1	0	1	0	0	1	0	1	1
IOWA	20	3	3	3	3	1	0	1	1	1	2	2
ILLINOIS	20	0	0	3	0	3	3	0	3	1	2	5
INDIANA	5	0	0	1	0	0	0	0	0	1	0	3
OHIO	1	0	0	0	0	0	0	0	0	0	0	1
PENNSYLVANIA	1	0	0	0	0	0	0	0	0	0	0	1
NEBRASKA	1	0	0	0	0	0	0	0	0	0	0	1
KANSAS	1	0	0	0	0	0	0	0	0	0	1	0
MISSOURI	13	0	1	1	0	2	0	0	1	3	0	5
VIRGINIA	2	0	0	0	0	0	0	0	0	0	0	2
ARKANSAS	17	0	0	3	2	1	1	0	0	3	0	7
TENNESSEE	2	0	0	0	1	0	1	0	0	0	0	0
NORTH CAROLINA	1	0	0	0	0	0	0	0	0	0	0	1
TEXAS	3	0	0	0	0	0	1	0	1	1	0	0
LOUISIANA	13	0	0	4	0	0	1	0	4	0	0	4
MISSISSIPPI	2	0	1	0	0	0	0	0	0	0	1	0
ALABAMA	1	0	0	0	0	0	0	0	0	0	0	1
TOTAL FOR BANDING DATA FROM MINNESOTA	514	18	36	45	11	26	25	24	34	84	51	160

FOOTNOTES:

THE FOLLOWING AOU, STATUS, AGE, AND SEX CODES WERE DETECTED FOR DATA IN THE ABOVE TABLE:

AOU	1320	
STATUS	300	370
AGE	4	
SEX	4	5

Fig. 1—Example of RCOVTAB output tabulating recoveries by calendar year and banding State, identifying State where recovered.

LLPLOT

LLPLOT is a FORTRAN program used to tabulate numbers of bandings or recoveries in 10 minute 1-degree, or 10-degree blocks. Numbers are printed in a 10 × 10 square grid according to the desired scale. Fig. 2 illustrates a tabulation by degree block of some of the data from Fig. 1. Each cell represents one block and the entire table depicts recoveries in the 10-degree block that includes the States of Minnesota and Iowa, portions of southern Manitoba and Ontario, western Wisconsin, northwestern Illinois, northern Missouri, and the eastern halves of North Dakota, South Dakota, and Nebraska. Over 80% of the recoveries in Fig. 1 occurred in this block. Fig. 2 shows data by recovery location; banding locations of recovered birds can be plotted in the same manner. LLPLOT requires 3,340 bytes of storage plus the EDITOR and system overhead.

BANDAREA

The FORTRAN program BANDAREA was designed to tabulate band recoveries within States or areas defined by latitude and longitude. The primary application of this program is to determine numbers and percentages of recoveries in a defined banding area as compared to those outside that area. Data are tabulated by species, age, sex, and year. If the area of interest is defined by latitude and longitude, it is possible to specify a third breakdown showing numbers and percentages of recoveries in an area of arbitrary width surrounding the central site. Up to 30 species and 30 recovery years are permissible per tabulation.

Data from Fig. 1 are tabulated in Fig. 3, which shows recoveries from a banding area defined by latitude and longitude. For this illustration, the banding area is defined as latitude 470–475 and

PLOT OF BAND RECOVERIES BY RECOVERY LOCATION BY 1 DEGREE BLOCK. LATITUDE 400-490, LONGITUDE 900- 990

LEGEND: CHIPPEWA BANDED LOCAL MALLARDS - DIRECT RECOVERIES

	1000–990	990–980	980–970	970–960	960–950	950–940	940–930	930–920	920–910	910–900
500–490	0	2	1	0	2	0	0	0	0	0
490–480	2	0	1	2	5	1	0	0	0	0
480–470	0	2	1	2	13	207	14	0	0	0
470–460	0	2	3	4	24	10	6	0	0	0
460–450	0	0	1	3	8	15	7	2	3	0
450–440	0	0	1	0	4	5	9	5	6	2
440–430	0	0	2	0	1	1	3	1	6	1
430–420	0	0	0	0	0	0	1	5	2	1
420–410	0	0	0	0	0	0	0	0	7	2
410–400	0	1	0	0	1	0	0	0	2	1

TOTAL RECOVERIES= 413

Fig. 2—Example of LLPLOT output tabulating recoveries occurring in the block defined by latitude 400–490 and longitude 900–990.

TABULATION OF RECOVERIES OCCURRING WITHIN BANDING BLOCK DEFINED BY LAT 470-475; LONG 940- 945. PAGE 1

SPECIES: MALLARD BANDED AS LOCAL CHIPPEWA BANDED LOCAL MALLARDS - DIRECT RECOVERIES

RECOVERY YEAR		TOTAL RECOVERIES	RECOVERED IN DEFINED AREA #	%	RECOVERED OUTSIDE AREA #	%	RECOVERED W/IN 1 DEG BLOCKS #	%
1962	MALES	8	3	37.50	5	62.50	0	0.0
	FEMALES	10	4	40.00	6	60.00	0	0.0
	TOTAL	18	7	38.89	11	61.11	0	0.0
1963	MALES	18	6	33.33	12	66.67	3	16.67
	FEMALES	18	9	50.00	9	50.00	1	5.56
	TOTAL	36	15	41.67	21	58.33	4	11.11
1964	MALES	26	4	15.38	22	84.62	5	19.23
	FEMALES	19	4	21.05	15	78.95	2	10.53
	TOTAL	45	8	17.78	37	82.22	7	15.56
1965	MALES	4	1	25.00	3	75.00	1	25.00
	FEMALES	7	1	14.29	6	85.71	0	0.0
	TOTAL	11	2	18.18	9	81.82	1	9.09
1966	MALES	15	6	40.00	9	60.00	2	13.33
	FEMALES	11	4	36.36	7	63.64	1	9.09
	TOTAL	26	10	38.46	16	61.54	3	11.54
1967	MALES	13	4	30.77	9	69.23	1	7.69
	FEMALES	12	6	50.00	6	50.00	1	8.33
	TOTAL	25	10	40.00	15	60.00	2	8.00
1968	MALES	7	3	42.86	4	57.14	2	28.57
	FEMALES	17	8	47.06	9	52.94	3	17.65
	TOTAL	24	11	45.83	13	54.17	5	20.83
1969	MALES	22	3	13.64	19	86.36	4	18.18
	FEMALES	12	4	33.33	8	66.67	1	8.33
	TOTAL	34	7	20.59	27	79.41	5	14.71
1970	MALES	42	24	57.14	18	42.86	6	14.29
	FEMALES	42	27	64.29	15	35.71	1	2.38
	TOTAL	84	51	60.71	33	39.29	7	8.33
1971	MALES	28	13	46.43	15	53.57	6	21.43
	FEMALES	23	16	69.57	7	30.43	2	8.70
	TOTAL	51	29	56.86	22	43.14	8	15.69
OTHER	MALES	104	30	28.85	74	71.15	25	24.04
	FEMALES	56	27	48.21	29	51.79	6	10.71
	TOTAL	160	57	35.62	103	64.37	31	19.37
TOTAL	MALES	287	97	33.80	190	66.20	55	19.16
	FEMALES	227	110	48.46	117	51.54	18	7.93
	TOTAL	514	207	40.27	307	59.73	73	14.20

Fig. 3—Example of BANDAREA output tabulating recoveries within the banding block defined by latitude 470–475 and longitude 940–945.

longitude 940–945. The option was chosen to tabulate recoveries occurring within one block from the banding area. BANDAREA requires 14,348 bytes of storage plus the EDITOR and system overhead.

The foregoing programs are written in FORTRAN IV and have been used on an IBM 360/50 (8-bits per byte) system. Under this configuration the system overhead ranges from 21,384 to 24,182 bytes, depending on the program. The next two programs were written in PL/1 because of its greater flexibility in output formatting. A generalized editor program has not been developed in PL/1, although both programs presented here are written to include such a package. Each program presently contains its own "EDITOR" subroutine to read data. Any detailed editing must be done beforehand. The FORTRAN EDITOR has an option to edit and copy, which can be used to create an edited file.

MAP

When large quantities of banding or recovery data are to be examined, it is often desirable to preview the geographical distribution of the data before attempting detailed analyses. The MAP program was designed to fill this need by producing a printer-plot of North America showing approximate recovery or banding locations. Numbers of recoveries at a given point are indicated by character over-printing to give a darkening gray-tone effect as numbers increase. The map is a 23.0 × 44.5 cm representation of North and Central America by a Lambert Azimuthal Equal-area projection centered at 40° N latitude, 100° W longitude.

Fig. 4 depicts a map plot of the data from Fig. 1. It shows at a glance where the recovery concentrations are located. Should actual numbers be needed, then

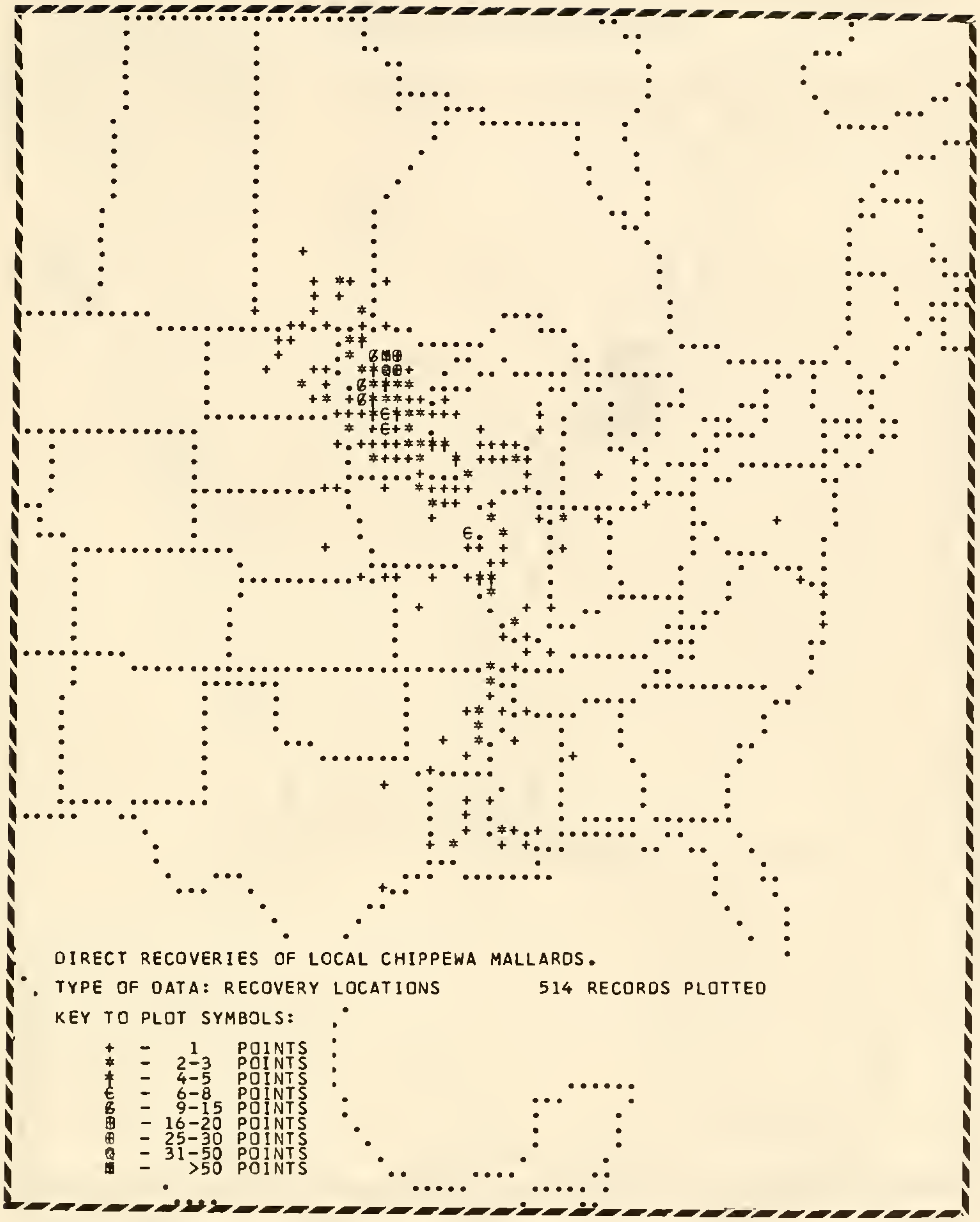

Fig. 4—Example of MAP output showing a portion of the printed representation of North America and band recovery plots.

LLPLOT can be run to cover the areas in question (Fig. 2). As an option, data expressed as a percentage of the total can be plotted to permit more realistic visual comparisons of different maps. MAP requires approximately 120,000 bytes of storage including system overhead.

Conversion of latitude and longitude to X and Y values for two-dimensional plotting involves some detailed trigonometric calculation. Cowardin (1977) discussed the formulae and rationale for their use with the Lambert Azimuthal Equal-area projection. Once calculated, X and Y can readily be converted to any map scale by multiplying by an appropriate constant. Subroutines to calculate X and Y have been developed in both FORTRAN and PL/1. Listings and descriptions are available from the author on request. Fig. 5 illustrates an application using the calculated X and Y values to plot recoveries on a preprinted map. The data from Fig. 4 are plotted by a WANG 720C calculator and a 25.4 × 38.1 cm flat-bed plotter. Similar applications can be programmed with computer-driven plotting software.

Fig. 5—Example of plotting on a preprinted map corresponding to the area shown in Fig. 4.

RCOVDIST

RCOVDIST tabulates distributions of two sets of recovery data for chi-square comparison as detailed by Cowardin (1977). Each set of recoveries is arranged into a 10 × 12 matrix according to distance and bearing from the banding site. Distances are grouped according to geometrically increasing values of 20, 40, . . . , and 5120 km. Bearings are subdivided into 12 cells defined by 30-degree increments.

The program produces a table for each set of recoveries and a 2 × k contingency table for χ^2 comparison. Chi-square and $V = \chi^2/N$ values are calculated as described by Cowardin (1977). RCOVDIST requires approximately 56,000 bytes of storage, including system overhead.

Listings and instructions for use of the programs discussed here may be obtained by writing the author at Northern Prairie Wildlife Research Center, P.O. Box 1747, Jamestown, North Dakota 58401. Other programs discussed by Cowardin and Davenport (1973) are also available.

LITERATURE CITED

Cowardin, L. M. 1977. Analysis and machine mapping of the distribution of band recoveries. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Wildl. 198. 8 pp.

Cowardin, L. M., and D. A. Davenport. 1973. Computerized system for organizing and maintaining files of banding data. Bird-Banding 44(3):187-195.

☆U.S. Government Printing Office: 1976-777-871/4 Region 8

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

EDITORIAL OFFICE
U.S. FISH AND WILDLIFE SERVICE
AYLESWORTH HALL, CSU
FORT COLLINS, COLORADO 80523

POSTAGE AND FEES PAID
U S DEPARTMENT OF THE INTERIOR
INT 423

U.S.MAIL